Chapter 6

Effects of Temperature Extremes on the Human Body

The human body is adapted to a narrow temperature range; it cannot function normally in hot and cold temperature extremes. Exposure to such extremes in the aviation environment impairs the efficiency of aircrews and adds to other stresses such as hypoxia and fatigue. Extreme climates can cause uncomfortable or unbearable cockpit conditions. Likewise, atmospheric temperature or altitude changes, aircraft interior ventilation and heating, and protective equipment can also create temperature extremes. This chapter briefly covers aviation operations in extreme climates; FM 3-04.202(1-202) contains an in-depth discussion of this subject.

SECTION I – HEAT

HEAT IN THE AVIATION ENVIRONMENT

HEAT EFFECTS

6-1. At times, aircrew members may have thought that the temperature inside their aircraft resembled that of a flying oven. Army aviation usually takes place at the relatively low altitudes that are associated with extremely high temperatures and humidity. Heat can seriously hamper mission requirements to accomplish complex tasks. In Army aviation, the potential for heat-stress problems is always present, not only because of unit locations but also because of Army aircraft construction.

KINETIC HEATING

6-2. During the flight, the aircraft structure is heated by friction between its surface and the air and by the rise in temperature caused by air compression in the front of the aircraft. Insulation in the cockpit and cabin air ductwork can reduce the effects of kinetic heating.

RADIANT HEATING

6-1. Solar radiant heat is the primary heat-stress problem in aircraft; the large expanses of glass or Plexiglas™ produce the greenhouse effect. This effect is caused by the differing transmission characteristics for radiation of differing wavelengths; thermal energy can become trapped within the cockpit. The temperatures in cockpits of aircraft parked on airfield ramps may be 50 to 60 degrees Fahrenheit higher than those in hangars because of the radiation of solar heating through transparent surfaces. This radiation, in turn, heats the interior objects of the cockpit. These heated objects then reradiate the waves at frequencies that cannot penetrate the glass or

Plexiglas™ outward. Therefore, heat accumulates within the cockpit and becomes a significant stress factor at altitudes below 10,000 feet.

ELECTRICAL HEAT LOADS AND COOLING SYSTEMS

6-4. With the development of new high-performance aircraft, the electrical heat load in the cockpit increases as more and improved avionics equipment is fitted into these aircraft. The greater the temperature in the cockpit, the greater the possibility of degraded performance.

6-5. Comfortable limits in the cockpit are 68 to 72 degrees Fahrenheit and 25 to 50 percent relative humidity. To maintain these temperatures and this humidity range, aircraft must have extra heating and cooling equipment. This equipment is expensive in both performance and cost. (A rule of thumb is that one pound of extra load requires nine pounds of structure and fuel to fly it.)

HEAT TRANSFER

TEMPERATURE REGULATION

6-6. The body maintains its heat balance with several mechanisms. These are radiation, conduction, convection, and evaporation.

RADIATION

6-7. Radiation involves the transfer of heat from an object of intense heat to an object of lower temperature through space by radiant energy. The rate of heat transfer depends mainly on the difference in temperature between the objects. If the temperature of the body is higher than the temperature of the surrounding objects, a greater quantity of heat is radiated away from the body than is radiated to the body.

CONDUCTION

6-8. Conduction is the transfer of heat between objects, in contact at different temperatures, from heated molecules (body) to cooler molecules of adjacent objects. The proximity of these objects will determine the overall rate of conduction.

CONVECTION

6-9. Convection is the transfer of heat from the body in liquids or gases in which molecules are free to move. During body-heat loss, the movement of air molecules is produced when the body heats the surrounding air; the heated air expands and rises because it is displaced by denser, cooler air. Respiration, which contributes to the regulation of body temperature, is a type of convection.

EVAPORATION

6-10. Evaporative heat loss involves the changing of a substance from its liquid state (sweat) to its gaseous state. When water on the surface of the body evaporates, heat is lost. Evaporation is the most common and usually the most easily explained form of heat loss.

LIMITATIONS

6-11. Radiation, convection, and conduction all suffer one major disadvantage in cooling the body; they become less effective as temperature increases. When the temperature of the air and nearby objects exceeds skin temperature, the body actually gains heat. This gain may be dangerous to the aviator.

6-12. When the temperature increases to about 82 to 84 degrees Fahrenheit, sweat production increases abruptly to offset the loss of body cooling through radiation, convection, and conduction. By the time the temperature reaches 95 degrees Fahrenheit, sweat evaporation accounts for nearly all heat loss.

6-13. Many factors affect the evaporation process. Some of these factors are—

- Protective clothing.
- Availability of drinking water.
- Relative humidity above 50 percent.
- Environmental temperature above 82 degrees Fahrenheit.

6-14. Relative humidity is the factor that most limits evaporation; at a relative humidity of 100 percent, no heat is lost by this mechanism. Although the body continues to sweat, it loses only a tiny amount of heat. For example, a person can function all day at a temperature of 115 degrees Fahrenheit and a relative humidity of 10 percent if given enough water and salt. If the relative humidity rises to 80 percent at the same temperature, that same person may be incapacitated within 30 minutes.

HEAT INJURY

6-15. The body will undergo certain physiological changes to counteract heat stress. To get heat from the inner body core to the surface where it can be lost to the surroundings, blood flow to the skin (cutaneous circulation) increases tremendously. Blood flow to other organs, such as the kidneys and liver, is reduced, and the heart rate is increased so that the body can maintain an adequate blood pressure. As the heat builds up, receptors in the skin, brain, and neuromuscular system are stimulated to increase sweat production. Normal heavy sweating produces one pint to one quart of sweat per hour; heat-stress conditions, however, can result in 3 to 4 quarts being produced. If a person does not replace this sweat loss by drinking liquids, the body rapidly dehydrates, the rate of sweat production drops, and the body temperature increases, causing further heat injury.

6-16. Individuals vary in their response to heat stress. Some serious reactions are heat cramps, heat exhaustion, and heatstroke. Factors that influence the physiological responses to heat stress include the amount of work that individuals perform and their physical condition as well as their ability to adapt to the environment. Old age, excessive alcohol ingestion, lack of sleep, obesity, or previous heatstroke can also diminish tolerance to heat stress. A previous episode of heatstroke can predispose an individual to repeated episodes.

PERFORMANCE IMPAIRMENT

6-17. Heat stress not only causes general physiological changes but also results in performance impairment. Even a slight increase in body temperature impairs an individual's ability to perform complex tasks such as those required to fly an aircraft safely. A body temperature of 101 degrees Fahrenheit roughly doubles an aviator's error rate. Generally, increases in body temperature have the following effects on an aviator:

- Error rates increase.
- Short-term memory becomes less reliable.
- Perceptual and motor skills slow, and the capacity to perform aviation tasks decreases.

HEAT-STRESS PREVENTION

6-18. By taking certain preventive measures, personnel can avoid heat stress. They can reduce their workload, replace lost water and salt, adapt to the environment, and wear protective clothing.

REPLACE WATER AND SALT LOSS

6-19. The human body cannot adjust to a decreased intake of water. People must replace water that is lost through sweating to avoid heat injury. The body normally absorbs water at the rate of 1.2 to 1.5 quarts per hour. A reasonable limit for the total consumption for a 12-hour workday is from 12 to 15 quarts. Therefore, additional water intake is required. Individuals should drink one quart per hour for severe heat-stress conditions or one pint per hour for moderate stress conditions. Executing activities at night can minimize water loss.

6-20. Salt loss is high in personnel who either have not adapted to the environment or have adapted but are subjected to strenuous activity under heat stress. Replenishing this salt is important. Normally, adding a little more salt to food during preparation is enough to replenish the salt level. If larger amounts are required, the flight surgeon should be consulted.

ADAPT TO THE ENVIRONMENT

6-21. Adaptation is essential to prevent heat injury. An individual who has not adapted to the environment is more susceptible to heat injury and disability; work performance will also decrease. A good plan of adaptation is based on a gradual increase in physical stress rather than a mere subjection of personnel to heat. A minimum of two weeks should be allowed for normal, healthy individuals to adapt; those who are less physically fit may require more time. Acclimation to heat can be attained in 4 to 5 days. Full heat acclimation takes from 7 to 14 days with two to three hours per day of carefully supervised exercise in the heat.

WEAR PROTECTIVE CLOTHING

6-22. In direct sunlight, an individual should wear loose clothing for adequate ventilation and evaporative cooling. In a hot environment, clothing protects an individual from solar radiation but reduces the loss of body heat from convection and conduction. Dark-colored clothing absorbs more radiant heat while light-colored clothing reflects it. To help reduce the heat load to the head, individuals should wear headgear to shade their head.

IN-FLIGHT HEAT-STRESS REDUCTION

6-23. Army aircrew members are required to work in hot cockpits. Their ability to handle a particular situation depends on the specific aircraft and the problem. If aircrews will be exposed to the heat for a long time, the only alternative may be to terminate the mission to prevent their incapacitation. However, aborting the mission is a last resort. Aircrews can minimize in-flight heat stress by increasing ventilation and continuing to replace fluids.

INCREASE VENTILATION

6-24. The pilot, more than any other crew member, must guard against heat stress. When speed and altitude permit, the pilot should open a window or canopy and direct the cool air entering the aircraft to his head and neck area to reduce heat buildup.

CONTINUE TO REPLACE FLUIDS

6-25. Fluid intake during flight helps prevent dehydration and makes up for profuse sweating. Crew members should be encouraged to drink fluids as conditions permit, especially in anticipation of periods of physical exertion.

SECTION II – COLD

COLD EFFECTS IN THE AVIATION ENVIRONMENT

6-26. Although heat stress causes Army aircrew members the most significant problems, they cannot overlook the physiological effects of cold on the body. Because Army aircrews must operate in all types of environments, they must understand how the body reacts to cold-temperature extremes. For example, during World War II, the U.S. Army experienced 90,535 cases of cold injury, including several thousand cases of high-altitude frostbite in aircrews. During the Korean Conflict, there were 9,000 cases of cold injury, 8,000 of which occurred in the first winter (1951 to 1952).

6-27. Many factors influence the incidence of cold injury. If troops are in a static defensive position, the incidence of injury drops because they have time to take care of their bodies. Individuals under 17 or over 40 years of age seem to have a predisposition to suffer cold injury as do those who have previously suffered from it. Fatigue level, organizational discipline, individual training and experience, and physiological factors all affect the tendency of individuals to experience cold injury. Nutrition, activity, and the ingestion of certain drugs and medications also influence the incidence of cold injury.

TYPES AND TREATMENT OF COLD INJURY

6-28. Hypothermia, trench foot (immersion foot), and frostbite are three types of cold injury that may affect aviators. A cold injury may be either superficial or deep.

6-29. Superficial cold injury usually can be detected by numbness, tingling, or pins-and-needles sensations. By acting on these signs and symptoms, individuals often can avoid further injury simply by loosening boots or other clothing and by exercising to improve circulation. In more serious cases involving deep cold injury, people may not be aware of a problem until the affected part feels like a stump or a block of wood.

6-30. Outward signs of cold injury include discoloration of the skin at the site of the injury. In light-skinned persons, the skin first reddens and then becomes pale or waxy white; in dark-skinned persons, the skin looks gray. An injured foot or hand feels cold to the touch. Swelling may also indicate deep injury. Soldiers should work in pairs—buddy teams—to check each other for signs of discoloration and other symptoms. Leaders should also be alert for signs of cold injuries.

6-31. First aid for cold injuries depends on whether the injury is superficial or deep. A superficial cold injury can be adequately treated by warming the affected part with body heat. This warming can be done by covering cheeks with hands, placing hands under armpits, or placing feet under the clothing of a buddy and next to his abdomen. The injured part should *not* be massaged, exposed to a fire or stove, rubbed with snow, slapped, chafed, or soaked in cold water. Individuals should avoid walking when they have cold-injured feet. Deep cold injury (frostbite) is very serious and requires more aggressive first aid to avoid or to minimize the loss of parts of the fingers, toes, hands, or feet. The sequence for treating cold injuries depends on whether the condition is life threatening. That is, removing the casualty from the cold is the *priority*. The other-than-cold injuries are treated at the same time as cold injuries while casualties are awaiting evacuation or are en route to a medical-treatment facility.

COLD-INJURY PREVENTION

6-32. Some general measures can be taken to prevent all types of cold injury. Individuals can—

- Keep their body dry.
- Limit exposure to the cold.
- Avoid wearing wet clothing.
- Monitor the windchill factor.
- Keep activity below the perspiration level.
- Avoid the direct contact of bare skin and cold metal.
- Use the buddy system to check for early signs of cold injury.
- Wear several layers of loose-fitting clothing to increase insulation and cold-weather headgear to prevent loss of body heat.

- Avoid alcohol intake because it dilates surface blood vessels; this dilation initially causes the body to feel warmer but, because of heat loss, actually chills it.

6-33. The windchill chart in Table 6-1 gives the time limits for exposure to the cold before individuals experience injury. This chart correlates wind velocities and ambient air temperatures and shows the resulting temperatures from the windchill factor. The same data apply when wet boots or wet clothing is worn or flesh is exposed. This chart also indicates the level below which frostbite becomes a real hazard. Trench foot, or immersion foot, can occur at any temperature shown on the chart, given the right combination of wind velocity and ambient air temperature.

Table 6-1. Windchill Temperatures

ESTIMATED WIND SPEED		ACTUAL TEMPERATURE READING (°F)											
		50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
(MPH)	(KNOTS)	EQUIVALENT CHILL TEMPERATURE (°F)											
Calm	Calm	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
5	5.75	48	37	27	16	6	-5	-15	-26	-36	-47	-57	-68
10	11.75	40	28	16	4	-9	-24	-33	-46	-58	-70	-83	-95
15	17.25	36	22	9	-5	-18	-32	-45	-58	-72	-85	-99	-112
20	23.00	32	18	4	-10	-25	-39	-53	-67	-82	-96	-110	-121
25	28.75	30	16	0	-15	-29	-44	-59	-74	-88	-104	-118	-133
30	34.50	28	13	-2	-18	-33	-48	-63	-79	-94	-109	-125	-140
35	40.25	27	11	-4	-20	-35	-51	-67	-82	-98	-113	-129	-145
40	46.00	26	10	-6	-21	-37	-53	-69	-85	-100	-116	-132	-148
(Wind speeds greater than 40 MPH or 46 knots have little additional effect.)		LITTLE DANGER Exposed *dry* flesh is not likely to freeze in less than one hour; the maximum danger is a false sense of security.				INCREASING DANGER Exposed flesh may freeze within one minute.			GREAT DANGER Exposed flesh may freeze within 30 seconds.				
		(Trench foot, or immersion foot, may occur at any point on this chart.)											

NOTES: 1. This chart was developed by US Army Research of Institute of Environmental Medicine, Natick, MA.
2. To convert a Celsius temperature reading to a Fahrenheit temperature reading, use the following formula: °F= °C x 9/5 + 32.
3. Measure or estimate the local temperature and wind speed. On this chart, find the temperature along the top and the wind speed along the left side. The intersection of the column and line gives the approximate equivalent chill temperature; for example, with a temperature of 20°F and a wind speed of 20 MPH (23 knots), the effect on exposed flesh is the same as a temperature of -10°F with no wind.